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WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

1989 LAKES AND RESERVOIR WATER QUALITY ASSESSMENT PROGRAM: SURVEY OF CHEMICAL CONTAMINANTS IN TEN WASHINGTON LAKES

by
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May 1990

Waterbody No. 23-9010

ACKNOWLEDGEMENTS

The Department of Ecology appreciates the cooperation of the National Park Service in allowing samples to be collected from Lake Crescent. The authors thank Duane Dickinson and Joe Fulks for their efforts in providing the fish samples from Lake Crescent, and Gail Ekenbarger for giving access to Kahlotus Lake. Brad Hopkins, Deborah Sargent, and Joan Hardy of Ecology provided valuable assistance in this project. Sonya Kirkendall did the word processing for the report.

ABSTRACT

Sportfish tissue (fillet) and bottom sediment samples from ten Washington State lakes were analyzed for EPA priority pollutants (except volatiles), herbicides, and organophosphorus pesticides. The level of chemical contamination was, with few exceptions, very low. Moderately elevated concentrations of mercury (0.54 mg/Kg, wet) and selenium (0.95 mg/Kg, wet) were found in largemouth bass from Black Lake and Osoyoos Lake, respectively. Low levels (0.7 - 210 ug/Kg, wet) of DDT compounds, primarily the metabolite DDE, were detected in most fish samples. On a lipid weight basis, the total DDT concentration in the Osoyoos fish sample was high enough to suggest potentially significant historical applications in this drainage. Sediment analysis showed an extremely high concentration of copper (1,010 mg/Kg, dry) in Steilacoom Lake--thought to be the result of past treatments with copper sulfate. Concentrations of copper, lead, antimony, cadmium, and silver were elevated in American Lake sediments. Organic compounds were infrequently detected in sediments and were limited to phenol, 4-methylphenol, fluoranthene, chrysene, and pyrene. Two organophosphorus pesticides, ethoprop and tebuthiuron, were also tentatively identified. Follow-up studies were recommended as a high priority in Steilacoom Lake and American Lake. Additional contaminant biomonitoring was recommended for Osoyoos Lake.

INTRODUCTION

The Washington Department of Ecology (Ecology), Toxics Investigations and Ground Water Monitoring Section conducted a survey of chemical contamination in ten Washington lakes as part of the 1989 EPA-sponsored Washington State Lakes and Reservoir Water Quality Assessment Program. The assessment program was proposed by Dave Hallock of Ecology's Ambient Monitoring Section and consisted of three components:

- o Citizen volunteers monitoring temperature and Secchi disc depth at 50 lakes

- o Conventional water quality sampling (hydrolab profiles, fecal coliform bacteria, chlorophyll-*a*, turbidity, and nutrients) of 25 lakes by Ecology's Surface Water Investigations Section (Brower and Kendra, 1990)

- o Toxics survey of ten lakes (present report).

The objective of the toxics survey was to assess the occurrence of potentially toxic metals and organic compounds in edible tissues of representative sportfish and in the bottom sediments, and to evaluate the significance of the findings. Lakes were selected for sampling by reviewing information on location, size, sportfishing, other recreational uses, residential development, and potential contaminant sources for 70 lakes. Under the sampling and analytical scheme developed for the study (described below) funding was sufficient to conduct complete surveys of nine lakes. These were selected by 1) targeting larger lakes with potential for chemical contamination, 2) giving first priority to lakes that were part of the citizen monitoring program, 3) avoiding lakes with existing toxics data, and 4) attempting to distribute sampling effort equitably across the state.

Table 1 lists the lakes that were surveyed. Their locations are shown in Figure 1. Non-point sources were the major contaminant concerns in seven of these lakes--urban runoff for Samish, American, and Black Lakes; agricultural runoff for Moses, Sprague, Kahlotus, and Osoyoos Lakes. Osoyoos also had past treatments with the herbicide 2,4-D to control Eurasian milfoil. Lake Crescent, in Olympic National Park, and Wenatchee Lake, in the Wenatchee National Forest, were chosen primarily for use as reference lakes removed from significant sources of chemical contamination. A sediment sample was also collected from a tenth lake, Steilacoom, to screen for accumulation of copper from past copper sulfate treatments to reduce heavy algal growth.

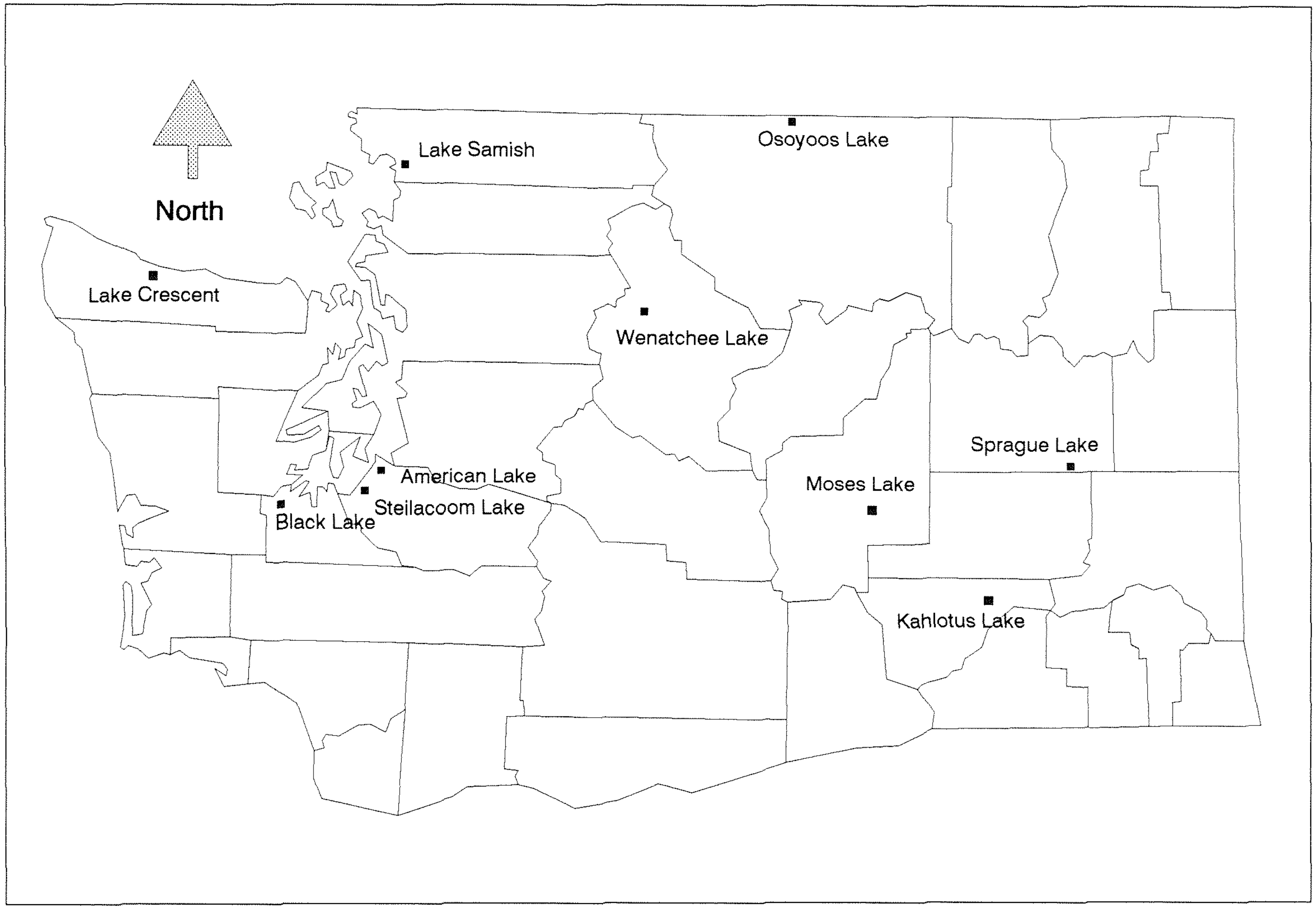


Figure 1: Locations of Lakes Surveyed for Chemical Contaminants.

METHODS

Sampling

Fish collection sites are shown in Figure 2. Fish were caught by electroshocking, or, in the case of Lake Crescent, hook and line. For each lake, an effort was made to collect five individuals of a major sportfish species. Table 2 shows the samples obtained. In five of the lakes--Samish, Black, Sprague, Kahlotus, and Osoyoos--largemouth bass was the dominant sportfish encountered in sufficient numbers for a sample. Electroshocking proved a poor method for catching sportfish in American, Wenatchee, and Moses Lakes where fish ultimately collected consisted of less sought after species--rock bass, lake whitefish, and black bullheads, respectively. The National Park Service required use of hook and line in Lake Crescent. Two cutthroat trout were obtained here through the assistance of local citizens.

Fish selected for analysis were individually wrapped in aluminum foil, placed in polyethylene bags, and stored on ice for one-to-three days before transport to the Ecology/EPA Manchester Laboratory where they were frozen. On completion of the field collections, the fish were thawed, rinsed with de-ionized water, and transferred to glass plates where fillets (skin-off) were removed with stainless steel knives and composited. Glass plates and knives were cleaned by washing with Liqui-Nox detergent followed by sequential rinses with de-ionized water, dilute nitric acid, de-ionized water and pesticide-grade acetone. Samples for metals analysis were homogenized by freeze-drying and grinding with mortar and pestle; organics samples were homogenized in a Waring blender. Sample containers were glass jars with teflon lid liners. These were obtained from I-Chem, Hayward, California and had been specially cleaned for trace metals and organics analysis (Series 300).

Bottom sediments were collected from two sites in each lake, except Steilacoom (Figure 2). Depth of sample collection ranged from eight feet in Moses and Kahlotus Lakes to approximately 140 feet in Lake Crescent and Wenatchee Lake. In most cases, samples were taken in deepest water at the upper (inlet) and lower (outlet) ends of the lakes. Both Osoyoos samples were collected in U.S. waters at the outlet end of the lake. The single Steilacoom Lake sample was also collected near its outlet.

Each sediment sample was a composite of the top 2-cm layer from three replicate grabs taken with a stainless steel 0.05 m^2 Ponar sampler. The composites were homogenized using stainless steel beakers and spoons, and split into subsamples for analysis. Sampling equipment cleaning and sample containers were as described above. The sediments were held on ice in the field and frozen on return to the Manchester Laboratory, except grain size samples which were refrigerated.

Chemical Analysis

Table 3 lists the target chemicals and ancillary variables analyzed in fish and sediment samples. Detection limits are shown for each chemical. A description of the analytical methods employed is provided in Table 4.

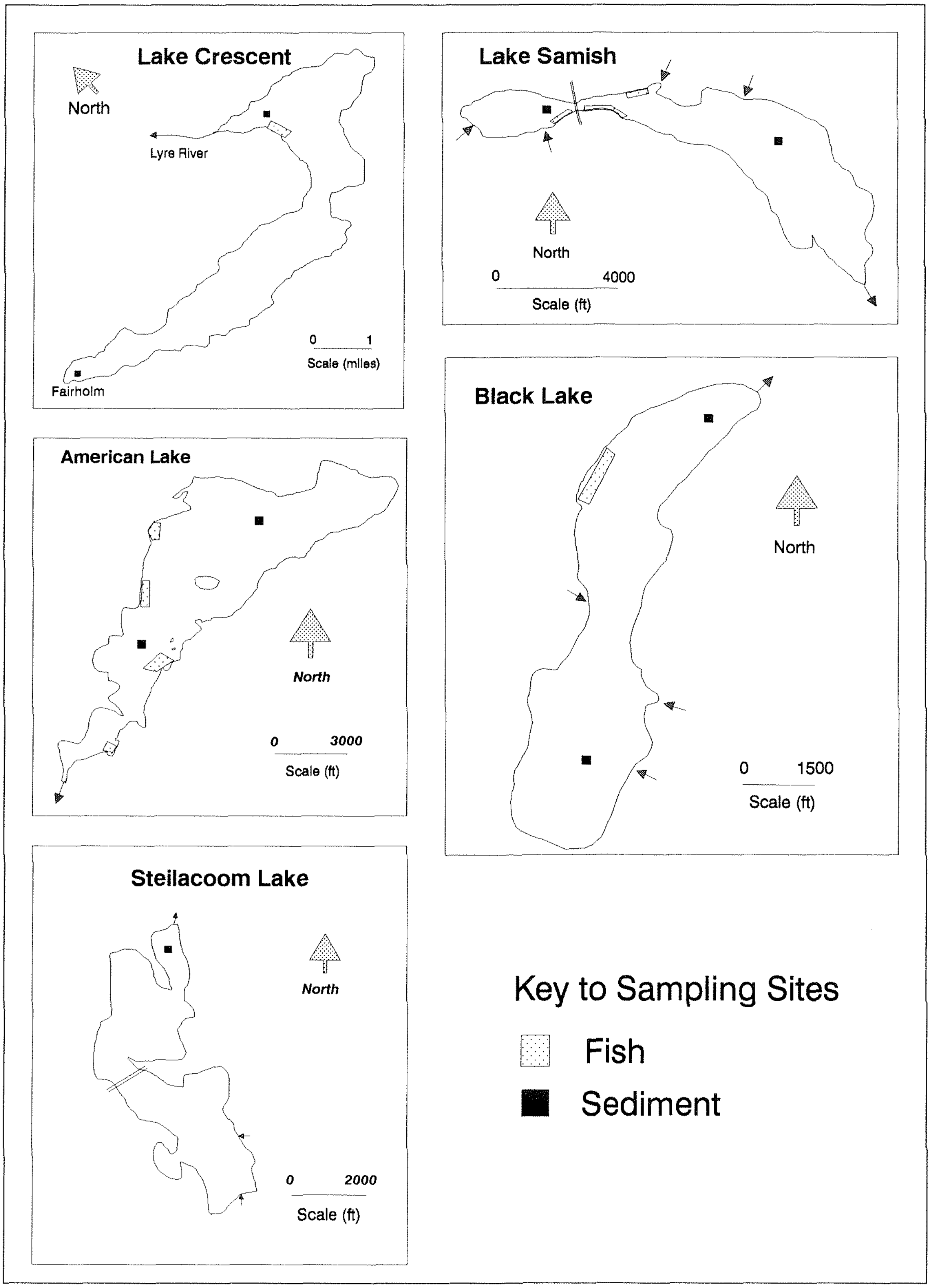


Figure 2a: Sampling Sites: Western Washington Lakes

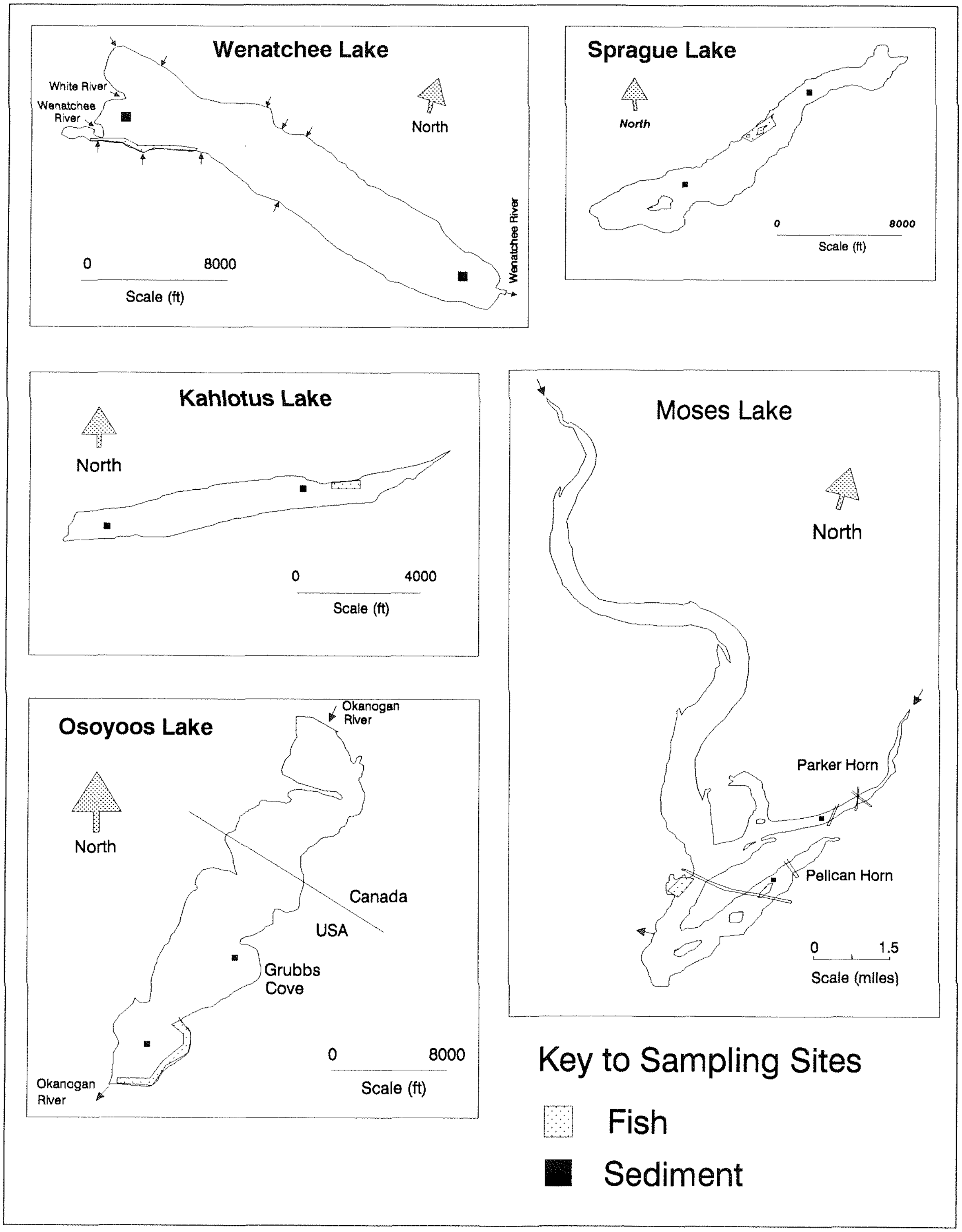


Figure 2b: Sampling Sites: Eastern Washington Lakes

Fish tissue was analyzed for arsenic, cadmium, copper, lead, mercury, selenium, zinc, organochlorine pesticides, polychlorinated biphenyls (PCBs), and percent lipid. Sediment analyses included the above metals plus chromium, nickel, antimony, silver, semi-volatile organics, herbicides, organophosphorus pesticides, total organic carbon (TOC), grain size, and percent solids. This analytical scheme generally follows what is considered to be the important fate process (bioaccumulation or sorption) for those chemicals classed as EPA priority pollutants (Callahan *et al.*, 1979). The herbicides and organophosphorus pesticides analyses include compounds classed as persistent to moderately persistent (Doull *et al.*, 1980) and recommended for monitoring in sediments of the Puget Sound basin (Tetra Tech, 1988).

Quality of the Data

The accuracy and precision of the data was assessed by examining results of surrogate spikes, duplicate matrix spikes, and method blanks, and through duplicate analysis of standard reference materials and field samples. The data were reviewed by Stuart Magoon and Craig Smith of the Manchester Laboratory. Holding times to extraction and analysis, matrix spike recoveries and precision, surrogate recoveries, and blank results were found acceptable (except as qualified below) and within prescribed limits of the EPA Contract Laboratory Program where applicable.

The analysis for organophosphorus pesticides in sediment was considered acceptable for purposes of screening for elevations in these compounds. The results, which showed the presence of the pesticides ethoprop and tebuthiuron in several samples, require some qualification. No multi-point calibration standard was run prior to injection of samples. Therefore, linearity could not be assessed, calling into question reported detection limits and quantitations. Positive detections were not confirmed on a second column. Finally, several of the standards used did not contain a reference peak (i.e., no surrogate). Without a reference peak for comparison of retention time between standards and samples, identification is questionable. The reported detection of ethoprop and tebuthiuron should, therefore, be regarded as tentative (Magoon, personal communication).

Results for standard reference materials (SRMs) analyzed in conjunction with field samples are given in Table 5. No SRMs were available for the organic compounds being analyzed. With the exception of arsenic in the sediment SRM, results were in close agreement with certified values showing the analyses were accurate. The arsenic results, coupled with low recovery (54%) in one of the matrix spikes (data not shown), indicate that arsenic analysis of the lake sediments underestimates actual concentrations.

Precision estimates derived from duplicate analysis of field samples are summarized in Table 6. The relative percent difference (RPD - range as percent of mean) between duplicates was within 20% for most analyses of fish tissue and sediments. This suggests sampling methods and laboratory analysis were not significant contributors to data variability for most analytes. Lower precision was achieved for selenium in tissue (RPD of 50%) and silver in sediment (RPD of 44%). In the case of selenium, poor precision may be a function of sample concentration (0.1 - 0.2 mg/Kg); an RPD of 11% was achieved for selenium in the fish tissue SRM (1.6 mg/kg). Organic compounds were not detected in the sediment duplicates.

RESULTS AND DISCUSSION

Fish Tissue

The metals concentrations measured in fish tissue are summarized in Table 7. Arsenic, cadmium, and lead were below detection limits (0.1, 0.002 and 0.02 mg/Kg, respectively) in all samples. Most tissues had low concentrations of selenium (<0.1 - 0.39 mg/Kg) and mercury (0.02 -0.27 mg/Kg). Copper (0.45 - 0.91 mg/Kg) and zinc (3.7 - 6.8 mg/kg) were present in the highest concentrations and were at similar levels in fish from all the lakes.

Selenium, copper, and zinc--unlike cadmium, lead, and mercury--are essential trace elements in fish (Merz, 1981), and, as such, are routinely detected in fish tissue. Of the latter three metals, only mercury is commonly reported to accumulate (as methylmercury) in the muscle tissue of fish (Schmitt and Finger, 1987; Ginn and Barrick, 1988). Arsenic is also a required mineral, but levels in freshwater fish are typically at or below the detection limits achieved during analysis of these samples (Eisler, 1988).

Fish samples from two lakes had moderately elevated concentrations of mercury or selenium. The mercury concentration in largemouth bass collected from Black Lake (0.54 mg/Kg) was higher than other lakes by factors of 2 to 10. The selenium concentration in largemouth bass from Osoyoos Lake (0.95 mg/Kg) was also elevated relative to other lakes, although not appreciably above that in whitefish (0.74 mg/Kg) from Wenatchee Lake, one of the reference lakes.

The mercury concentration in the Black Lake fish sample is probably a reflection of the age of the fish. These were the largest bass encountered in the survey. Approximate weights of specimens in the composite sample were 2, 3-1/2, 4, and 5-3/4 pounds. Mercury is unique among metals in being magnified between trophic levels in aquatic food chains. As a result, the highest concentrations occur in long-lived carnivorous species. It is not unusual for largemouth bass, lake trout, or walleye to have mercury concentrations of 1 mg/Kg or more (Eisler, 1987). The National Academy of Sciences (1973) has recommended that mercury concentrations in fish should not exceed 0.5 mg/Kg for protection of fish-eating wildlife.

Results of the most recent survey by the U.S. Fish and Wildlife Service (USFWS), National Contaminant Biomonitoring Program (Lowe *et al.*, 1985) show that fish samples collected from 112 stations nation-wide in 1980 - 1981 had a geometric mean selenium concentration of 0.47 mg/Kg with a range of 0.09 - 2.47 mg/Kg. USFWS data from collections spanning 1972 - 1981 have consistently shown 85th percentile concentrations of selenium in fish to be in the range of 0.7 - 0.9 mg/Kg (Walsh *et al.*, 1977; May and McKinney, 1981; Lowe *et al.*, 1985). USFWS samples are whole fish which would be expected to have higher selenium concentrations than skeletal muscle (Sato *et al.*, 1980). Based on these data and tabulations of selenium levels in freshwater biota found in Eisler (1985), the selenium concentration of 0.95 mg/Kg in the Osoyoos fish samples appears somewhat elevated.

The review of Baumann and May (1984), however, shows muscle tissue of fish from high selenium environments typically contains 10 - 20 mg/Kg. These authors place the upper limit of normal selenium concentrations in fish at 1.5 mg/Kg and conclude that toxic effects do not become a concern for fish until concentrations exceed 2 mg/Kg. In the absence of industrial sources such as fly ash from coal-fired power plants and mining/smelting of nickel-copper ore, agricultural runoff from lands with selenium-rich soils is usually the major factor responsible for aquatic selenium toxicity (Ohlendorf, 1989).

With the exception of trace amounts of DDT and its metabolites DDE and DDD, organochlorine pesticides and PCBs were not detected in fish from any of the lakes. The concentrations of DDT compounds measured in the fish samples are shown in Table 8. DDT compounds, principally the DDE metabolite, were detected in fish from all lakes except Samish and American. Concentrations of total DDT (DDT+DDE+DDD) ranged from 0.7 to 210 ug/Kg, with the highest concentration being in largemouth bass from Osoyoos Lake. The parent compound DDT constituted a small fraction of the total DDT in all samples where residues were detected, indicating the source(s) are historical.

Uptake of DDT compounds by fish occurs primarily through the gills; there is little convincing evidence of magnification through the food chain (Konasewich *et al.*, 1982). Concentrations in fish are primarily a function of lipid content. Figure 3 shows lipid-normalized total DDT concentrations to better compare results between lakes. On a lipid-normalized basis, the Osoyoos Lake fish are higher than the next highest sample, Moses Lake black bullheads, by a factor of 5 (19,000 vs. 3,800 ug/Kg lipid). This suggests Osoyoos has a much higher ambient level of DDT compounds than the other lakes.

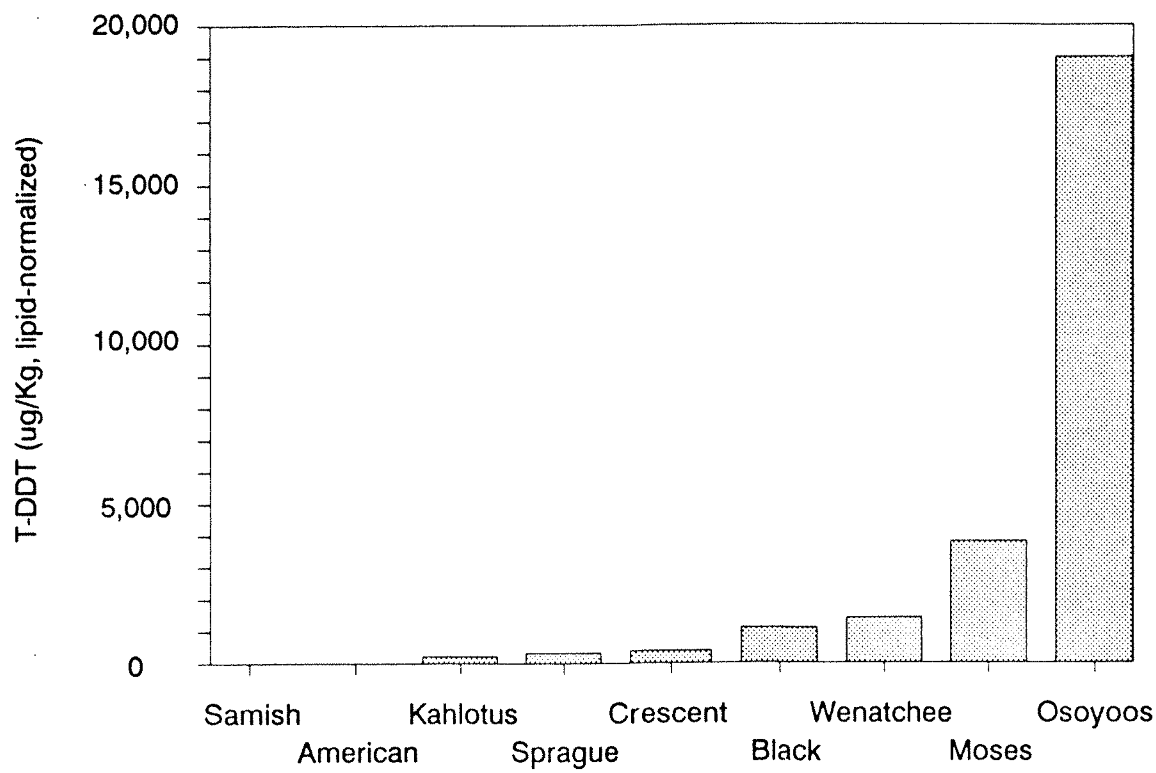


Figure 3. Comparison of Lipid-Normalized Total DDT (DDT+DDE+DDD) Concentrations in Fish Tissue Samples

A total DDT concentration of 210 ug/Kg on a wet weight basis is not considered extremely high. The National Academy of Sciences recommendation for protection of aquatic wildlife is that total DDT concentrations should be less than 1,000 ug/Kg (wet) in any aquatic plants or animals (NAS, 1973). The geometric mean concentration for whole fish during the above-mentioned USFWS 1980 -1981 survey was 290 ug/Kg (Schmitt *et al.*, 1985). DDT and/or its metabolites were present in one or more samples from every USFWS station.

On the other hand, a lipid-normalized concentration of 19,100 ug/Kg does appear elevated. The USFWS geometric mean total DDT concentrations for surveys between 1976 and 1981 ranged from 3,600 - 4,300 ug/Kg lipid (Schmitt *et al.*, 1985). Locally, the lower Yakima River has some of the highest DDT residues reported in Washington fish. Results of a 1985 Ecology survey (Johnson *et al.*, 1986) showed average total DDT concentrations in nine muscle tissue samples from lower Yakima River fish to be 9,800 ug/Kg lipid; the maximum value was 18,000 ug/Kg lipid which compares closely to the Osoyoos sample. A similar Ecology survey in Lake Chelan which, like the Yakima River, has a history of DDT use in its drainage basin, showed even higher lipid-normalized concentrations in edible fish tissue, in the range of 15,000 - 99,000 ug/Kg lipid in the four samples analyzed (Patmont *et al.*, 1989).

Other than the three instances of moderately elevated concentrations noted above, the level of contaminants in fish samples collected for the present survey was very low. Based on analysis of metals, chlorinated pesticides, and PCBs, fish from the seven lakes selected because of their potential for chemical contamination were, for the most part, indistinguishable from fish collected from the two reference lakes.

It follows that the fish samples were well within levels considered acceptable for human consumption. Table 9 shows action levels of the U.S. Food and Drug Administration (FDA, 1985) and median legal limits of other countries (Nauen, 1983) for fish marketed commercially. By reason of the unusually large specimens analyzed, there is probably little significance to the finding that mercury in the Black Lake fish sample was at the median international legal limit of 0.5 mg/Kg.

Bottom Sediments

Data on the general physical/chemical characteristics of the lake sediments are in Table 10. Grain size distribution of the samples is depicted in Figure 4. The sediments were primarily silt. Both Wenatchee Lake samples and one sample each from Osoyoos Lake (Grubbs Cove) and Lake Crescent (off Fairholm) were mostly sand. Except for Crescent and Osoyoos, the relative amounts of sand, silt and clay were similar at both sampling sites within each lake.

The TOC data suggest organic enrichment in three lakes. Sediments from American (6.8 - 14%), Black (9.0 - 12%), and Steilacoom (13%) Lakes had a high TOC content relative to the other lakes (1.0 - 7.1%). Ecology's analysis of the water quality data obtained for these lakes during 1989 showed Steilacoom and Black to be eutrophic and American to be mesotrophic-to-eutrophic (Brower and Kendra, 1990).

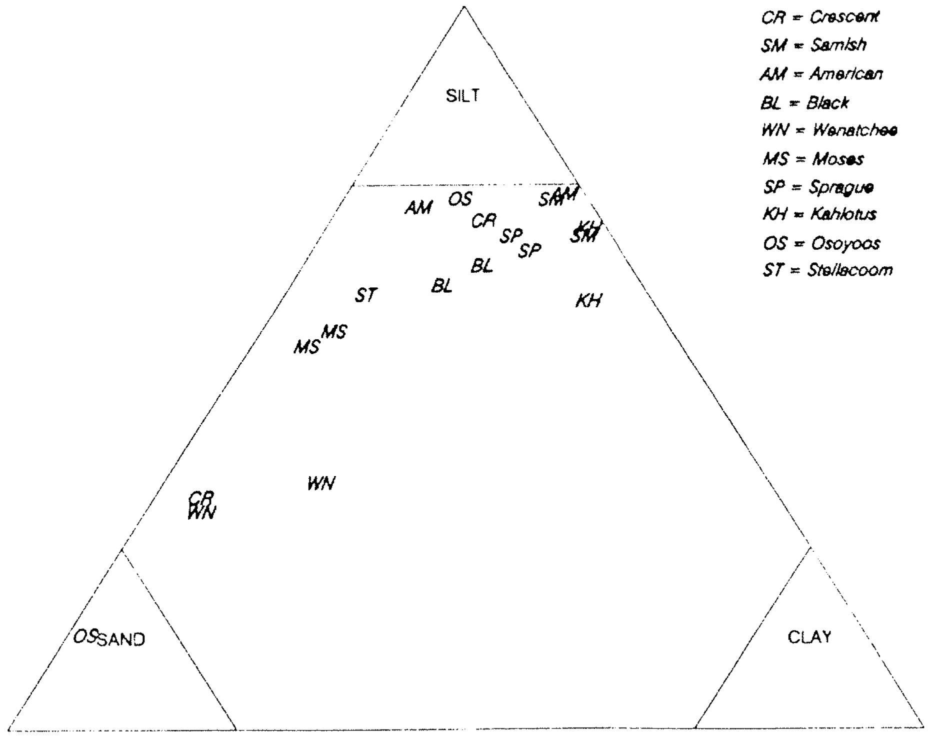


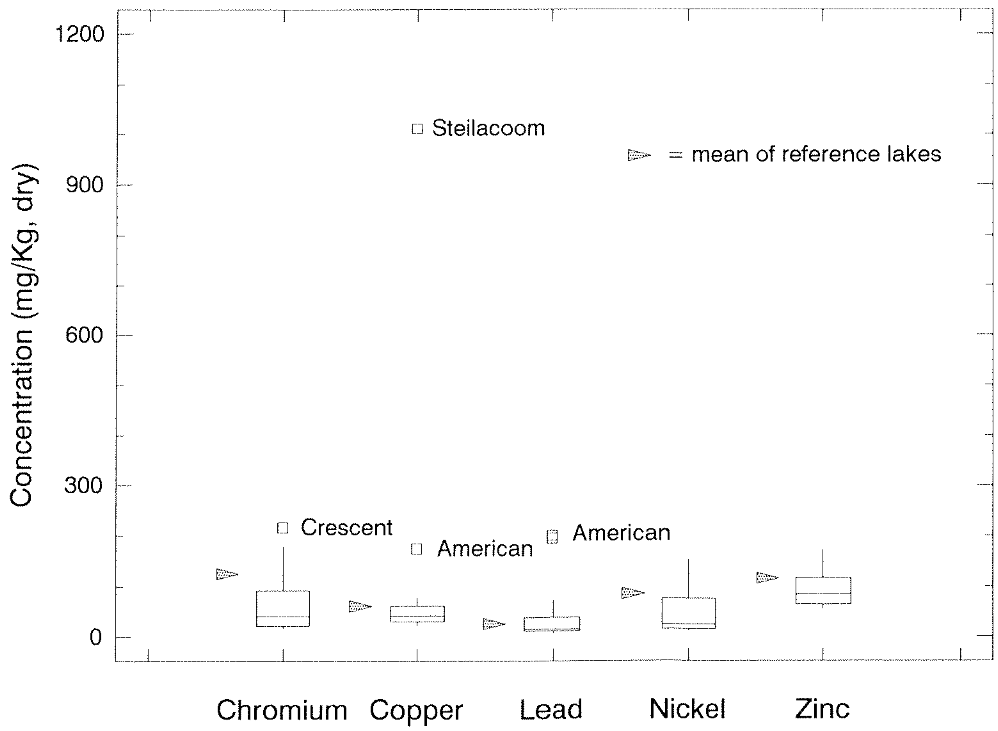
Figure 4. Grain Size Distribution of the Lake Bottom Sediments

Table 11 shows the results of metals analysis. In most instances, metals concentrations, like grain size, were similar at both sampling sites in each lake.

The detection limits achieved for mercury (0.06 - 0.56 mg/Kg) and selenium (0.47 - 0.70 mg/Kg) were not sufficiently low to quantify concentrations of these metals in sediment. With regard to concerns raised by moderately elevated mercury and selenium concentrations in fish samples from Black Lake and Osoyoos Lake, concentrations of these metals in freshwater sediments considered to be uncontaminated are usually less than 1 mg/Kg (Eisler, 1985, 1987).

The sediment data were examined for elevated metals concentrations by "box and whisker" plots (Figure 5). In these diagrams, the box covers the middle 50% (lower and upper quartiles) of the data values, with the center line at the median. The whiskers extend to points within 1.5 times the interquartile range; outliers are plotted as separate points. An arrow was added to mark average concentrations measured in the two reference lakes.

Metals concentrations in the reference lakes were generally near median values, but were not consistently the lowest of the lakes. The Lake Crescent sample collected off Fairholm had the highest chromium concentration (215 mg/Kg). This may be related to the high sand content of this sample. It is probably more indicative of local mineralogy than chemical contamination.



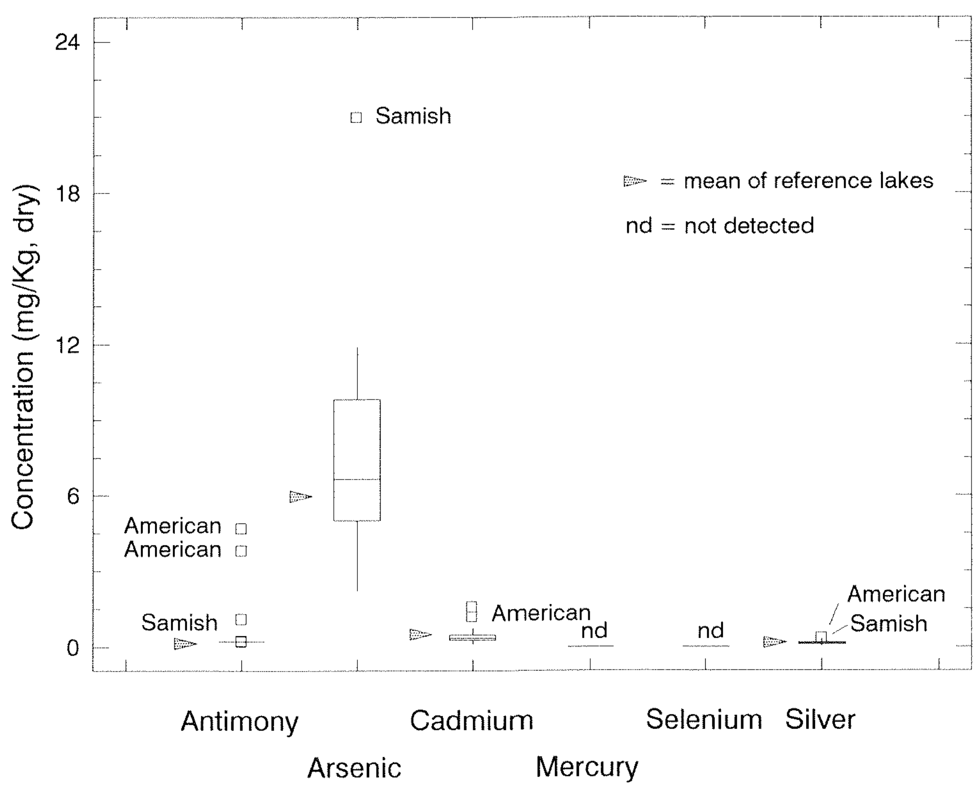


Figure 5. Box and Whisker Plots of Metals Concentrations in the Lake Bottom Sediments (see text)

An extremely high concentration of copper (1,010 mg/Kg) was found in the single sample collected from the outlet of Steilacoom Lake, very likely due to previously mentioned copper sulfate treatments for algae control. A concentration of this magnitude may be biologically significant. Hanson and Stefan (1984) observed the disappearance of macrophytes and reduced abundance of benthic invertebrates in Minnesota Lakes receiving prolonged copper sulfate treatments. Copper concentrations in the sediments of these lakes were in the approximate range of 300 - 5,600 mg/Kg.

American Lake sediments appeared to be contaminated with several metals. Both sampling sites had similarly elevated concentrations of lead (193 - 199 mg/Kg), antimony (3.8 - 4.7 mg/Kg), cadmium (1.2 - 1.6 mg/Kg), and silver (0.34 - 0.36 mg/Kg). The sample at the south (outlet) end of American Lake was also high in copper (173 mg/Kg)--Ecology records show this lake has also been treated with copper compounds. Arsenic (21.0 mg/Kg), antimony (1.1 mg/Kg), and silver (0.24 - 0.36 mg/Kg) were elevated in Lake Samish, although American Lake sediments were higher in both antimony and silver. These concentrations are an order of magnitude above concentrations in the reference lakes, except silver which is elevated by two to five times above reference.

Relatively few compounds were detected during organics analysis of the sediments. Table 12 summarizes the results.

4-Methylphenol was detected most frequently, being quantified in one or both samples from five lakes--Samish (1,500 ug/Kg), Black (420 -720 ug/Kg), Wenatchee (74 ug/Kg), Moses (910 - 1,600 ug/Kg), and Kahlotus (59 ug/Kg). Phenol (190 - 280 ug/Kg) was also detected in Kahlotus. These are both naturally occurring chemicals formed during degradation of biological material. Human-caused sources are many and include auto exhaust, asphalt, domestic sewage, and use as disinfectants. They are commonly detected in aquatic sediments and generally considered to have low toxicity to aquatic organisms (O'Connor and Stanford, 1979).

American Lake and Lake Samish had trace amounts of the polyaromatic hydrocarbons (PAH) fluoranthene, chrysene, and pyrene. Concentrations were in the range of 71 - 470 ug/Kg with the highest concentrations occurring at the south end of American Lake. These ubiquitous chemicals are among those most frequently detected in aquatic sediments near urban/industrial areas, combustion of fossil fuels being a major source. Their detection in American and Samish Lakes probably reflects contamination by urban runoff.

Trace amounts of the soil insecticide ethoprop (trade name Mocap) were tentatively identified in sediments of Black Lake (4.4 ug/Kg) and Osoyoos Lake (6.7 ug/Kg). Slightly higher concentrations of the herbicide tebuthiuron (trade name Spike) were also tentatively identified in American (120 ug/Kg), Moses (110 ug/Kg), and Kahlotus (52 ug/Kg) Lakes. Tebuthiuron has a relatively low toxicity to aquatic life (LC_{50}s of 112 mg/L and 144 mg/L to bluegill and rainbow trout, respectively); it is considered a concern in aquatic environments primarily due to persistence in the sediments (Tetra Tech, 1988). Ethoprop has a low aquatic persistence. No information was found on its toxicity to freshwater life.

Based on the above data, the high copper concentration in Steilacoom Lake and the elevated levels of several chemicals in American Lake stand out among the ten lakes surveyed. There are presently no criteria specifically developed to address the biological significance of chemical contamination of freshwater sediments. Additional biological evaluation is, therefore, recommended (see below).

SUMMARY OF FINDINGS BY LAKE AND RECOMMENDATIONS

Steilacoom Lake

The high concentration of copper in the single sediment sample analyzed, coupled with a history of copper sulfate treatments, warrants an intensive survey to evaluate potential adverse biological effects. Such a survey should include assessment of benthic invertebrate populations, bioassays of the sediments, and analysis of copper in water samples. This survey should also address the rate of attenuation of copper in the water column and downstream transport following treatment with copper compounds

American Lake

Like the majority of the lakes surveyed, there was no evidence of chemical contamination in fish tissue. However, concentrations of copper, lead, antimony, cadmium, and silver were elevated in the sediments relative to other lakes. This was one of two lakes where PAH were detectable in the sediments and one of three lakes were the pesticide tebuthiuron was tentatively identified. On this basis, additional sampling is recommended to better define the distribution and sources of contamination. Biological evaluation of the sediments should, at a minimum, include bioassay. Additional data on American Lake is a particular priority in light of recent blooms of toxic algae (*Anabaena flos-aqua*).

Osoyoos Lake

The primary finding of interest was a moderately elevated selenium concentration and a high concentration of total DDT compounds (on a lipid weight basis only) in fish tissue. There was no evidence of sediment contamination, except for tentative identification of the pesticide ethoprop in one sediment sample. No residues were detected from past treatments with 2,4-D. The fish tissue results suggest this lake may be a good candidate for Ecology's annual biological monitoring program (Hopkins *et al.*, 1985).

Lake Samish

The fish tissue sample had no unusual metals concentrations and no detectable organochlorine pesticides or PCBs. Samish sediments had a higher arsenic concentration than other lakes. It was also one of two lakes where PAH were detected in the sediments. The second highest 4-methylphenol concentration was measured in one of the two sediment samples from this lake, but was not detected in the companion sample. The levels of these several chemicals do not, however, appear sufficiently high to recommend additional study.

Black Lake

An elevated mercury concentration was measured in fish tissue, probably a reflection of the older age of the fish sampled rather than evidence of mercury contamination. Results of sediment analysis showed no indication of significant chemical contamination. In common with several other lakes, 4-methylphenol and ethoprop (tentatively identified) were detected in the sediments.

Moses Lake

Fish tissue and sediments had no significant elevations in metals. A low concentration of DDT compounds was detected in the fish sample. The highest 4-methylphenol concentrations in sediments from the survey lakes occurred here. The significance of this finding cannot be evaluated at present and, in and of itself, is not considered to represent significant contamination. Tebuthiuron was tentatively identified in one sediment sample.

Sprague Lake

Based on the chemicals analyzed in the present survey, this was among the least contaminated of the lakes. It was comparable to Crescent and Wenatchee in metals concentrations and in the absence of detectable levels of organic contaminants in fish and sediment samples.

Kahlotus Lake

Except for trace amounts of phenol, 4-methylphenol, and tebuthiuron (tentatively identified) in sediment, fish and sediment from this lake appeared uncontaminated.

Lake Crescent/Wenatchee Lake

Save for what is probably a naturally occurring elevation in chromium in one of the sediment samples collected in Lake Crescent, these lakes appeared to have no significant elevations in levels of the chemicals analyzed.

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TABLES

Table 1. Lakes surveyed for chemical contaminants.

Lake	Sampling Date (1989)	County	Area (acres)	Mean Depth (feet)
Crescent	August 23*	Clallam	5,127	--
Samish	August 22	Whatcom	680	31
American	August 21	Pierce	1,125	53
Black	July 12	Thurston	576	19
Wenatchee	July 26	Chelan	2,445	150
Moses	July 24	Grant	6,800	19
Sprague	July 25	Adams	1,841	11
Kahlotus	July 24	Franklin	321	14
Osoyoos	July 25	Okanogan	5,729	46
Steilacoom	August 22	Pierce	313	11

- Lake Crescent fish samples were collected in September.

Table 2. Fish samples analyzed.

Lake	Common Name	Scientific Name	Number of Individuals	Size Range (total length in mm)
Crescent	Cuthroat Trout	*Salmo clarki*	2	485 - 505
Samish	Largemouth Bass	*Micropterus salmoides*	5	210 - 300
American	Rock Bass	*Ambloplites rupestris*	5	145 - 200
Black	Largemouth Bass	*Micropterus salmoides*	4	380 - 515
Wenatchee	Lake Whitefish	*Coregonus clupeaformis*	5	200 - 265
Moses	Black Bullhead	*Ictalurus melas*	5	285 - 350
Sprague	Largemouth Bass	*Micropterus salmoides*	5	310 - 415
Kahlotus	Largemouth Bass	*Micropterus salmoides*	5	230 - 255
Osoyoos	Largemouth Bass	*Micropterus salmoides*	4	290 - 410

Table 3. Target chemicals (detection limits).

A. Fish Tissue

1. Organochlorine Pesticides*
(ug/Kg, wet; ppb)

4,4'-DDT (2.0)
4,4'-DDE (2.0)
4,4'-DDD (2.0)
Methoxychlor
Aldrin (1.0)
Endrin (2.0)
Endrin Ketone (3.0)
Dieldrin (2.0)
Gamma-Chlordane (1.5)
Alpha-Chlordane (1.5)
Heptachlor (1.0)
Heptachlor Epoxide (1.0)
Alpha-BHC (1.0)
Beta-BHC (1.0)
Delta-BHC (1.5)
Gamma-BHC (1.0)
Endosulfan I (1.0)
Endosulfan II (2.0)
Toxaphene (150)

2. PCBs*
(ug/Kg, wet; ppb)

Arochlor-1242/1016 (20)
Arochlor-1248 (20)
Arochlor-1254 (20)
Arochlor-1260 (20)

3. Metals*
(mg/Kg, wet; ppm)

Arsenic (0.08-0.13)
Cadmium (0.002)
Copper (0.01)
Lead (0.02)
Mercury (0.01)
Selenium (0.1)
Zinc (0.1)

4. Ancillary Variables

Percent Lipid

B. Sediments

1. Semi-volatiles*
(ug/Kg, dry; ppb)

Phenol (40-230)
bis(2-Chloroethyl)Ether (40-230)
2-Chlorophenol (53-310)
1,3-Dichlorobenzene (27-150)
1,4-Dichlorobenzene (27-150)
Benzyl Alcohol (67-380)
1,2-Dichlorobenzene (27-150)
2-Methylphenol (53-310)
bis(2-Chloroisopropyl)Ether (40-230)
4-Methylphenol (53-310)
N-Nitroso-Di-n-Propylamine (67-380)
Hexachloroethane (67-380)
Nitrobenzene (40-230)
Isophorone (27-150)
2-Nitrophenol (80-460)
2,4-Dimethylphenol (53-310)
Benzoic Acid (330-1900)
bis(2-Chloroethoxy)Methane (27-150)
2,4-Dichlorophenol (40-230)
1,2,4-Trichlorobenzene (40-230)
Naphthalene (24-150)
4-Chloroaniline (53-310)
Hexachlorobutadiene (67-380)
4-Chloro-3-Methylphenol (67-380)
Acenaphthene (27-150)
2,4-Dinitrophenol (120-690)
4-Nitrophenol (350-2000)
Dibenzofuran (27-150)
2,4-Dinitrotoluene (93-540)
2,6-Dinitrotoluene (80-460)
Diethylphthalate (27-150)
4-Chlorophenyl-phenylether (40-230)
Fluorene (27-150)
4-Nitroaniline (120-690)
4,6-Dinitro-2-Methylphenol (120-690)
N-Nitrosodiphenylamine(1) (40-230)
4-Bromophenyl-phenylether (67-380)
Hexachlorobenzene (40-230)
Pentachlorophenol (67-380)
Phenanthrene (41-230)
Anthracene (27-150)
Di-n-Butylphthalate (27-150)
Fluoranthene (27-150)
Pyrene (27-150)
Butylbenzylphthalate (40-230)
3,3'-Dichlorobenzidine (130-800)
Benzo(a)Anthracene (27-150)
bis(2-Ethylhexyl)Phthalate (48-150)

* EPA priority pollutants

Table 3. (continued)

B. Sediments

1. Semi-volatiles*
   (ug/Kg, dry; ppb)

2-Methylnaphthalene (27-150)
Hexachlorocyclopentadiene (53-310)
2,4,6-Trichlorophenol (53-310)
2,4,5-Trichlorophenol (53-310)
2-Chloronaphthalene (27-150)
2-Nitroaniline (110-620)
Dimethyl Phthalate (27-150)
Acenaphthylene (27-150)
3-Nitroaniline (110-620)
Chrysene (27-150)
Di-n-Octyl Phthalate (27-540)
Benzo(b)Fluoranthene (27-150)
Benzo(k)Fluoranthene (27-150)
Benzo(a)Pyrene (27-150)
Indeno(1,2,3-cd)Pyrene (27-150)
Dibenz(a,h)Anthracene (27-150)
Benzo(ghi)Perylene (53-310)

2. Chlorinated Herbicides
   (ug/Kg, dry; ppb)

Silvex (1.0-2.0)
2,4,5-T (2.0-4.0)
Dinoseb (2.0-4.0)
Dicamba** (1.0-3.0)
Dichlorprop (4.0-20)
2,4-D** (4.0-22)
2,4-DB (10-20)
Dalapon (200-660)
MCPP (500-2000)

3. Organophosphorus Pesticides
   (ug/Kg, dry; ppb)

Dichlorvos (6.0-43)
EPTC (6.0-37)
Mevinphos (13-90)
Systox (11-74)
Ethoprop (3.0-11)
Diazinon** (1.5-11)
Disulfoton (1.5-11)
Ronnel (11-75)
Alachlor (12-85)
Metribuzin (6.0-38)
Chlorpyrifos** (4.0-27)
Methyl Parathion (30-220)
Fenthion (10-69)
Malathion (6.0-43)
Tetrachlorvinphos (17-120)
Fensulfothion (7.0-48)
Hexazinon (4.0-27)
Coumaphos (83-590)
Atrazine** (4.0-27)
Prometon** (5.0-32)
Pronamide** (20-140)
Simazine** (27-190)
Trifluoralin** (6.0-37)
Tebuthiuron** (110-140)

4. Metals*
   (mg/Kg, dry; ppm)

Arsenic (0.1-0.2)
Antimony (0.45-0.50)
Cadmium (0.01-0.03)
Chromium (0.1-0.2)
Copper (0.1-0.2)
Lead (0.1-0.2)
Mercury (0.06 -0.56)
Nickel (0.1-0.2)
Selenium (0.47-0.70)
Silver (0.01)
Zinc (0.1-0.2)

5. Ancillary Variables

Percent Moisture
Grain Size
Percent Total Organic Carbon

* EPA priority pollutants

** Recommended for monitoring in sediments of Puget Sound basin (Tetra Tech, 1988)

Table 4. Analytical methods.

Analyte	Method	Reference	Laboratory
1. Fish Tissue			
Percent lipids	Gravimetric	EPA, 1980	Analytical Resources, Inc., Seattle, WA
As,Cu,Se,Zn	X-Ray Fluoresence	Neilson, 1983	Battelle Northwest
Cd,Pb	GFAA	EPA, 1983	Sequim, WA
Hg	CVAA	EPA, 1983	" "
Organochlorine Pesticides/PCBs	GC/ECD #8080	EPA, 1986 Inc., Seattle, WA	Analytical Resources,
2. Sediment			
Percent Moisture	Dry @ 105 #209F	APHA, 1985	Analytical Resources, Inc., Seattle, WA
Grain Size	Seives and Pipettes	Holme, 1971	Laucks Testing Laboratories, Seattle, WA
Total Organic Carbon	Combustion/CO_2	Tetra Tech, Inc., 1986	Analytical Resources, Inc., Seattle, WA
Ag,As,Cd,Pb,Sb,Se	GFAA	EPA, 1985	" " "
Cr,Cu,Ni,Zn	ICP	" "	" " "
Hg	CVAA	" "	" " "
Semivolatile Organics	GC/MS #8270	EPA, 1986	" " "
Chlorinated Herbicides	GC/ECD #8150	" "	" " "
Organophosphorus Pesticides	GC/NPD #8140	" "	" " "

Table 5. Duplicate analysis of standard reference materials.

1. Fish Tissue (mg/Kg; ppm)

Standard Reference Material	Source	Zinc	Copper	Mercury	Selenium	Arsenic	Lead	Cadmium
Dogfish Muscle DORM - 1	Nat'l Research Council Canada	19.3	5.98	0.781	1.70	18.0	0.54	0.085
"	"	20.0	6.40	0.734	1.52	17.5	0.37	0.090
Certified Value =		21.3	5.22	0.798	1.62	17.7	0.40	0.086
		± 1.0	± 0.33	± 0.074	± 0.12	± 2.1	± 0.12	± 0.012

2. Sediment (mg/Kg; ppm)

Standard Reference Material	Source	Zinc	Copper	Chromium	Nickel	Lead
Buffalo River Sed. NBS-2704	Nat'l Bureau of Standards	402	97	114	42	142
"	"	422	98.8	120	43	156
Certified Value =		438	98.6	135	44.1	161
		± 12	± 5	± 5	± 3	± 17

Standard Reference Material	Source	Arsenic	Antimony	Cadmium	Silver	Mercury	Selenium
Buffalo River Sed. NBS-2704	Nat'l Bureau of Standards	11.2	2.3	3.8	NA	1.4	NA
"	"	13.4	3.5	3.6	NA	1.3	NA
Certified Value =		23.4	3.79	3.45	NA	1.44	NA
		± 0.8	± 0.15	± 0.22		± 0.07	

NA - Not Analyzed

Table 6. Duplicate analysis of field samples.

1. Fish Tissue - Metals (mg/Kg, wet; ppm)

Lake	Species	Zinc	Copper	Mercury	Selenium	Lead	Cadmium
Moses	Black Bullhead	4.0	0.48	0.02	0.20	0.02U	0.002U
"	"	4.5	0.57	0.02	0.12	0.02U	0.002U
Relative Percent Difference[a] =		12%	17%	50%	50%	---	---

2. Fish Tissue - Organics (ug/Kg, wet; ppb)

Lake	Species	% Lipid	4,4'-DDE	4,4'-DDD
Moses	Black Bullhead	1.2	28	9.0
"	"	0.9	29	9.0
Relative Percent Difference =		29%	3.5%	0%

3. Sediment - General Physical/Chemical Characteristics

Lake	Location	%Moisture	%Gravel	%Sand	%Silt	%Clay	%Total Organic Carbon
Moses	Parker Horn	64.7	<2	38	54	8.0	1.8
"	"	64.8	<2	36	56	8.0	1.9
Relative Percent Difference =		0.2%	0%	3.6%	5.4%	0%	5.4%

4. Sediment - Metals (mg/Kg, dry; ppm)

Lake	Location	Zinc	Copper	Chromium	Nickel	Lead
Samish	W. Arm	143	54.2	96.1	78	72
"	"	143	48.1	93.9	74	74
Relative Percent Difference =		0%	12%	2.3%	5.3%	2.7%

		Arsenic	Antimony	Cadmium	Silver	Mercury	Selenium
Samish	W. Arm	20.1	1.1	0.80	0.36	0.25U	0.49U
"	"	22.0	0.99	0.70	0.23	0.20U	0.50U
Relative Percent Difference =		9.0%	10%	13%	44%	---	---

a - Range as percent of duplicate mean.
U - Not detected at detection limit shown.

Table 7. Metal concentrations in edible fish tissue (mg/Kg, wet; ppm).

Lake	Species	Arsenic	Cadmium	Lead	Mercury	Selenium	Zinc
Crescent	Cutthroat Trout	0.13U	0.002U	0.02U	**0.22**	**0.39**	**4.7**
Samish	Largemouth Bass	0.09U	0.002U	0.02U	**0.27**	**0.29**	**4.5**
American	Rock Bass	0.12U	0.002U	0.02U	**0.19**	0.11U	**5.9**
Black	Largemouth Bass	0.09U	0.002U	0.02U	**0.54**	0.11U	**3.7**
Wenatchee	Lake Whitefish	0.13U	0.002U	0.02U	**0.03**	**0.74**	**4.7**
Moses	Black Bullhead	0.08U*	0.002U*	0.02U*	**0.02***	**0.16***	**4.2***
Sprague	Largemouth Bass	0.09U	0.002U	0.02U	**0.11**	0.10U	**4.2**
Kahlotus	Largemouth Bass	0.12U	0.002U	0.02U	**0.14**	**0.33**	**6.8**
Osoyoos	Largemouth Bass	0.08U	0.002U	0.02U	**0.07**	**0.95**	**4.7**

U - Not detected at detection limit shown.
* - Mean of duplicates, or lower detection limit.

Table 8. DDT compounds in edible fish tissue (ug/Kg, wet; ppb).

Lake	Species	%Lipid	4,4'-DDT	4,4'-DDE	4,4'-DDD	Total DDT
Crescent	Cutthroat Trout	**1.5**	**0.6J**	**5.2**	2.0U	**5.8**
Samish	Largemouth Bass	**0.2**	2.0U	2.0U	2.0U	2.0U
American	Rock Bass	**0.3**	2.0U	2.0U	2.0U	2.0U
Black	Largemouth Bass	**0.6**	2.0U	**6.0**	**0.5J**	**6.5**
Wenatchee	Lake Whitefish	**1.7**	**4.7**	**18**	**1.5J**	**24**
Moses	Black Bullhead	**1.0**	2.0U*	**28***	**9.0***	**38**
Sprague	Largemouth Bass	**0.4**	2.0U	**0.7J**	2.0U	**1.3**
Kahlotus	Largemouth Bass	**0.3**	2.0U	**0.7J**	2.0U	**0.7**
Osoyoos	Largemouth Bass	**1.1**	**5.7**	**150**	**55**	**210**

J - Estimated concentration.
U - Not detected at detection limit shown.
* - Mean of duplicates, or lower detection limit.

Table 9. Legal limits in commerical fishery products for chemicals detected in fish tissue samples.

Chemical	Concentration Range Observed In Present Survey	FDA Action Level[a]	Median International Limit[b]
Mercury (mg/Kg, wet)	0.02 - 0.54	1.0	0.5
Selenium (mg/Kg, wet)	<0.10 - 0.95	--	1.0
Zinc (mg/Kg,wet)	3.7 - 6.8	--	50
DDT (ug/Kg, wet)	<2.0 - 5.7	5000	5000
DDE (ug/Kg, wet)	0.7 - 150	5000	5000
DDD (ug/Kg, wet)	0.5 - 55	5000	5000

[a] FDA (1985)
[b] Nauen (1983)

Table 10. General characteristics of the sediments.

Lake	Location	Depth (feet)	%Moisture	Grain Size %Gravel (>2mm)	%Sand (2mm-62um)	%Silt (62um -4um)	%Clay (<4um)	% Total Organic Carbon
Crescent	off Lyre R.	75	48.5	<2	13	71	17	3.4
"	off Fairholm	140	51.1	<2	63	32	5	1.0
Samish	West Arm	102	80.5	<2	3	68	29	7.0
"	East Arm	71	78.1	<2	4	73	23	4.6
American	North End	78	92.2	<2	12	64	24	6.8
"	South End	53	71.4	<2	19	72	9	14.0
Black	North End	20	86.7	<2	22	62	17	9.0
"	South End	20	88.8	<2	16	64	20	12.0
Wenatchee	West End	138	64.9	<2	64	30	6	2.7
"	East End	90	59.6	<2	49	34	17	1.0
Moses	Parker Horn	8	64.8*	<2*	37*	55*	8*	1.8*
"	Pelican Horn	10	58.9	<2	41	53	6	1.6
Sprague	West End	15	80.8	<2	10	66	24	5.2
"	East End	17	79.3	<2	11	68	21	3.9
Kahlotus	West End	9	59.0	<2	2	70	29	2.2
"	East End	8	76.9	<2	7	59	34	3.8
Osoyoos	Grubbs Cove	39	58.8	<2	85	13	2	1.4
"	South End	40	78.5	<2	14	74	13	3.5
Steilacoom	Near Outlet	11	91.4	<2	31	60	9	13.0

* - Mean of duplicates.

Table 11. Metals concentrations in the sediments (mg/Kg, dry; ppm).

Lake	Location	Zinc	Copper	Chromium	Nickel	Lead	Arsenic	Antimony	Cadmium	Silver	Mercury	Selenium
Crescent	Off Lyre R.	64.1	53.5	74.8	41	6.7	4.8	0.46U	0.19	0.06	0.20U	0.46U
"	Off Fairholm	103	72.4	215	90	13.8	5.9	0.48U	0.27	0.03	0.06U	0.48U
Samish	West Arm	143*	51.2*	95.0*	76*	73*	21.0*	1.1*	0.75*	0.30*	0.20U*	0.49U*
"	East Arm	116	40.4	91.4	79	51	11.7	0.49U	0.59	0.24	0.16U	0.49U
American	North End	150	60.7	19.8	16	193	11.9	4.7	1.2	0.36	0.56U	0.70U
"	South End	161	173	32.2	18	199	11.9	3.8	1.6	0.34	0.51U	0.53U
Black	North End	67.9	27.6	46.6	29	34	9.8	0.49U	0.40	0.10	0.42U	0.49U
"	South End	63.8	23.7	36.3	24	39	7.1	0.49U	0.47	0.14	0.37U	0.49U
Wenatchee	West End	94.5	42.0	129	80	11.6	7.1	0.49U	0.36	0.14	0.09U	0.49U
"	East End	172	78.4	179	154	13.8	6.2	0.48U	0.45	0.16	0.12U	0.48U
Moses	Parker Horn	67.6	38.3	21.3	14	10.2	4.3	0.48U	0.30	0.07	0.10U	0.48U
"	Pelican Horn	60.6	22.3	20.9	12	11.1	2.2	0.47U	0.12	0.10	0.09U	0.49U
Sprague	West End	55.2	30.2	18.1	12	12.0	2.9	0.48U	0.12	0.08	0.30U	0.48U
"	East End	62.5	33.2	21.1	14	12.8	5.0	0.49U	0.17	0.07	0.18U	0.49U
Kahlotus	West End	94.9	44.4	32.8	22	16.1	7.3	0.45U	0.35	0.18	0.10U	0.45U
"	East End	85.5	39.3	26.6	19	15.1	5.6	0.48U	0.30	0.13	0.18U	0.48U
Osoyoos	Grubbs Cove	60.3	26.4	49.4	24	15.9	8.2	0.47U	0.30	0.09	0.08U	0.47U
"	South End	83.9	43.0	61.3	35	19.0	6.2	0.50U	0.41	0.17	0.19U	0.50U
Steilacoom	Near Outlet	NA	1,010	NA	NA	NA	NA	NA	NA	NA	NA	NA

U - Not detected at detection limit shown.
NA - Not analyzed.
* - Mean of duplicates, or lower detection limit.

Table 12. Organic compounds detected in the sediments (ug/Kg, dry; ppb).

		Semi-volatiles					Pesticides	
Lake	Location	Phenol	4-Methylphenol	Fluoranthene	Chrysene	Pyrene	Ethoprop**	Tebuthiuron**
Crescent	Off Lyre R.	48 U	79 U	32 U	32 U	32 U	2.5 U	33 U
"	Off Fairholm	29 U	37 U	9 U	19 U	19 U	1.5 U	18 U
Samish	West Arm	77 U	**1500**	**100**	**110**	**81**	4.0 U	100 U
"	East Arm	65 U	87 U	65 U	110 U	44 U	3.0 U	38 U
American	North End	44 U	59 U	**95**	59 U	**71**	2.5 U	**120**
"	South End	200 U	270 U	**470**	**300 J**	**340**	11 U	140 U
Black	North End	83 U	**420**	56 U	83 U	56 U	**4.4**	50 U
"	South End	110 U	**720**	71 U	110 U	71 U	6.0 U	75 U
Wenatchee	West End	40 U	**74 J**	27 U	27 U	27 U	2.0 U	25 U
"	East End	36 U	48 U	24 U	24 U	24 U	2.0 U	25 U
Moses	Parker Horn	41 U	**910**	27 U	27 U	27 U	5.0 U	170 U
"	Pelican Horn	58 U	1600	39 U	39 U	39 U	3.0 U	**110**
Sprague	West End	78 U	100 U	52 U	52 U	52 U	2.0 U	25 U
"	East End	230 U	310 U	150 U	150 U	150 U	6.0 U	75 U
Kahlotus	West End	**190 J**	**59 J**	24 U	24 U	24 U	2.0 U	25 U
"	East End	**280 J**	70 U	35 U	35 U	35 U	3.0 U	**52**
Osoyoos	Grubbs Cove	33 U*	44 U*	22 U*	22 U*	22 U*	**6.7*****	110 U
"	South End	110 U	140 U	72 U	72 U	72 U	17 U	40 U

J - Estimated concentration.
U - Not detected at detection limit shown.
* - Lower detection limit achieved in duplicate.
** - Detection and quantification of these compounds is tentative.
*** - Not detected in duplicate (9.0U).